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MODIFIED-ATMOSPHERE EFFECTS ON THE MARKET QUALITY OF LETTUCE SHIPPED BY RAIL

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MODIFIED-ATMOSPHERE EFFECTS ON THE MARKET QUALITY OF LETTUCE SHIPPED BY RAIL

By J. K. Stewart, *horticulturist;* M. J. Ceponis, *plant pathologist;* and L. Beraha, *plant pathologist, Market Quality Research Division, Agricultural Research Service*

SUMMARY

Test shipments of head lettuce were sent in 12 paired railcars or paired trailers on flatcars from California and Arizona to East Coast markets during 1967 and 1968. The purpose of the tests was to compare the market quality of lettuce held in modified atmospheres (MA) and in normal atmospheres (NA) during transit.

The cars and trailers in which the atmospheres had been modified had low oxygen and above normal carbon monoxide concentrations during transit. This modified atmosphere was established after loading by purging the car or trailer with nitrogen to lower the oxygen level and by adding carbon monoxide afterwards. Bags of lime were placed in the load compartments to absorb carbon dioxide produced by respiration of the lettuce.

No attempt was made to modify the atmosphere in the normal-atmosphere cars and trailers.

All cars and trailers had conventional mechanical refrigeration equipment and all lettuce was vacuum precooled before loading.

Transit temperatures averaged 37° F. in both the MA and NA vehicles. Temperature differences between the warmest and coolest locations in the vehicles averaged 3°.

At shipping point, the oxygen concentrations in the MA cars and trailers averaged about 2 to 3 percent. The carbon monoxide averaged 1.3 percent.

At destination, the oxygen concentrations in the MA and NA vehicles averaged 6.9 and 18.3 percent, respectively.

The only quality factor significantly affected by the two different atmospheres in this study was pink rib. The incidence of pink rib was significantly lower (5-percent probability level) in lettuce shipped in the MA vehicles than in lettuce shipped in NA vehicles. However, pink rib data were limited to two tests only.

Russet spotting was not prevalent enough in these tests to justify statistical analyses. However, previous laboratory and shipping tests with low-oxygen atmospheres have shown that modified atmospheres similar to those studied were effective in reducing russet spotting of lettuce predisposed to this disorder.

External appearance, butt discoloration, decay, and tipburn were not significantly influenced by the atmosphere in transit.

A disorder of lettuce not reported previously in commercial shipments was observed in lettuce from both the MA and the NA vehicles. We have named the disorder "brown stain." Pictures and a description of this disorder are included. It was associated with carbon dioxide concentrations above about 2 percent at destination.

INTRODUCTION

Railcars and trailers equipped for the transport of fresh produce in modified atmospheres have been available to lettuce shippers on the west coast since about 1964. Some of these modified-atmosphere systems have been tested previously by the U.S. Department of Agriculture.[1] [2] One such system introduces nitrogen into the load compartment during transit to refrigerate the load and also to maintain a low oxygen (O_2) level. Another system previously tested introduces nitrogen (N_2) into the load compartment, during transit only, to maintain a low O_2 level; the load in this system is refrigerated by conventional mechanical equipment.

A third system for maintaining modified atmospheres in transit was tested in 1967 and 1968 by the USDA for lettuce shipments. In this system the O_2 concentration is lowered by purging the load compartment with nitrogen after the car or

[1] Stewart, J. K., Harvey, J. M., Ceponis, M. J., and Wright, W. R. *Nitrogen—Its Effect on Transit Temperatures and Market Quality of Western Lettuce Shipped in Piggyback Trailers.* U.S. Dept. Agr. Market. Res. Rpt. 759, 14 pp. 1966.

[2] Stewart, J. K., and Ceponis, M. J. *Effects of Transit Temperatures and Modified Atmospheres on Market Quality of Lettuce Shipped in Nitrogen-Refrigerated and Mechanically Refrigerated Trailers.* U.S. Dept. Agr. Market. Res. Rpt. 832, 9 pp. 1968.

trailer is loaded. No additional nitrogen is introduced during transit. After the initial purge, carbon monoxide (CO) is also introduced into the car or trailer and lime is placed in the vehicles to absorb the carbon dioxide (CO_2) produced by the lettuce during respiration. The vehicles are tightly sealed to reduce air leakage through doors, drains, and other openings.

This report presents the results of tests conducted to determine the effectiveness of this particular system in maintaining the market quality of lettuce and to further evaluate the merits of modified atmospheres for lettuce during transcontinental shipment.

METHODS

Twelve paired normal atmosphere (NA) and modified atmosphere (MA) test shipments are evaluated in this report. Eight pairs were shipped in railcars and four were shipped in trailers on flatcars. Ten of the pairs originated in the Salinas area of California and two in the Salt River Valley in Arizona (table 1). All of the vehicles were shipped to the New York marketing area except two, which were shipped to Philadelphia, Pa.

Additional paired shipments made in this series of tests are not evaluated in this report (except in relation to brown-stain lesions) because of mechanical failure in transit or a high leak rate in the MA vehicle, or because 2 or more days elapsed between the recovery of the test packages in the two vehicles in a given test shipment.

Twelve cartons of lettuce were obtained from the same field to serve as test packages for each paired test shipment. Six cartons were placed in the cars or trailers with normal atmospheres and the other six were placed in cars or trailers in which the atmosphere was to be modified for the tests.

Recording thermometers were placed in the test packages, which were located at various positions in the load, to provide a record of the transit temperatures. Average transit temperatures were based on the temperature readings at 12-hour intervals from the day of loading to the day of unloading. This time interval ranged from 6 to 9 days, except for trailers 17 and 18, which were not unloaded until the 14th day after loading. In the cars, temperatures were measured at the bottom, middle, and top layers at the quarterlength position in each end of the car. In the trailers, temperatures were measured at the middle and top layers at the front; at the bottom, middle, and top layers at the half-length; and in the top layer at the rear of the trailer. All thermometers were in the center row. In the test shipments from Arizona,

TABLE 1.—*Shipping dates, originating points, and destinations of 12 paired shipments of lettuce sent in rail vehicles with modified and with normal atmospheres from western sources to east coast markets, 1967–68* [1]

Type and No. of vehicle,[2] and vehicle's atmosphere	Shipping date	Originating point and destination of shipment
Railcar:		
No. 1, modified atmosphere	Sept. 19, 1967	Salinas (Calif.) to Harlem River (N.Y.)
No. 2, normal atmosphere	do	Salinas to Brooklyn (N.Y.)
No. 3, modified atmosphere	May 14, 1968	Salinas to New York City
No. 4, normal atmosphere	do	Do.
No 5, modified atmosphere	May 27, 1968	Do.
No. 6, normal atmosphere	do	Salinas to Philadelphia
No. 7, modified atmosphere	July 10, 1968	Salinas to New York City
No. 8, normal atmosphere	do	Salinas to Philadelphia
No. 9, modified atmosphere	July 23, 1968	Salinas to New York City
No. 10, normal atmosphere	do	Do.
No. 11, modified atmosphere	Sept. 10, 1968	Do.
No. 12, normal atmosphere	do	Do.
No. 13, modified atmosphere	Nov. 26, 1968	Mesa (Ariz.) to New York City
No. 14, normal atmosphere	do	Glendale (Ariz.) to Harlem River
No. 15, modified atmosphere	Nov. 27, 1968	Mesa to New York City
No. 16, normal atmosphere	do	Do.
Trailer on flatcar:		
No. 17, modified atmosphere	Aug. 23, 1967	Salinas to New York City
No. 18, normal atmosphere	do	Do.
No. 19, modified atmosphere	May 28, 1968	Do.
No. 20, normal atmosphere	do	Do.
No. 21, modified atmosphere	July 16, 1968	Do.
No. 22, normal atmosphere	do	Do.
No. 23, modified atmosphere	Aug. 24, 1968	Do.
No. 24, normal atmosphere	do	Salinas to Jersey City

[1] Each paired shipment contained 12 cartons of lettuce from the same field; 6 cartons were shipped in vehicles with modified atmospheres and 6 were shipped in vehicles with normal atmospheres.

[2] All railcars were 50 feet long (inside) except for car No. 14, which was 44½ feet long. Both railcars and trailers were mechanically refrigerated and had foamed-in-place insulation.

only three temperatures were measured, all in the top layer at the doorway area where the six test packages assigned to each vehicle were located.

Inside air temperatures were measured at the ceilings of most vehicles and ambient temperatures were measured with recording thermometers attached under one of each pair of vehicles in most tests. Average inside air temperatures were based on temperature readings at 6-hour intervals from the day of loading to the day of unloading. Only the minimum and maximum outside air temperatures were averaged.

Before modifying the atmospheres in the MA cars and trailers, seals and plastic liners were placed at the door openings to help prevent air leakage. Drains and other openings also were tightly sealed. In each vehicle, a large plastic bag was suspended from the ceiling and connected to the outside air by a tube. This bag permitted an equalization of pressures between the outside and the inside of the vehicle during altitude changes in transit and prevented an excessive loss of the modified atmosphere.

The MA vehicles also contained bags of lime in cartons placed on top of the loads to absorb CO_2 given off during respiration. During the 1967 and early 1968 tests, 150 pounds of lime were placed in each MA car and 100 pounds were placed in each MA trailer. During the 1968 season, the amounts of lime included in the MA vehicles were increased until twice the amount used in 1967 was being used.

After being loaded and sealed, the MA car or trailer was purged with N_2 to lower the O_2 concentration. When the desired O_2 level was approached, CO was added.

Test packages were recovered at destination for market-quality evaluations by USDA personnel. The first examination was made as soon as possible after the test cartons were recovered; the second examination was made after the packages had been held for an additional 4 days at 50° F. One layer of lettuce from each carton was used for the first evaluation and the other layer was used for the second examination.

When all the test cartons in a paired shipment could not be recovered on the same day, those received first were held in the laboratory at 38° F. until the rest could be recovered. If receipt was delayed over 1½ days, data from such tests were omitted from this report. Among the tests evaluated, the average time from recovery of the test cartons until the first examination was about 13 hours for lettuce from the MA vehicles and about 8 hours for lettuce from the NA vehicles.

Quality evaluations were made for each head of lettuce from the test cartons. Each head was rated for firmness, for general external appearance with and without wrapper leaves, and for butt discoloration. Firmness ratings were: 1, very soft; 2, soft; 3, firm; 4, very firm; and 5, hard. Appearance ratings were 1, unsalable; 2, poor; 3, fair; 4, good; and 5, excellent. Butt discoloration ratings were: 1, none; 2, trace; 3, slight; 4, moderate; and 5, severe. Head firmness, which in lettuce is an indication of maturity, was rated the same (firm to very firm) in test lots recovered from both the modified and normal atmosphere vehicles.

Each head of lettuce was torn completely apart during examination and examined for pink rib, decay, tipburn, russet spotting, rib discoloration, and any other visible defect. A head was scored whenever one of these disorders was considered severe enough to be objectionable to a consumer.

Weight change during transit was determined in five of the tests by weighing each test carton after vacuum cooling and at time of arrival.

Data were analyzed statistically with a computer. In the analysis of variance, data from each pair of vehicles were considered a replication. However, for the analysis of the data for pink rib, which occurred in only two tests, each carton was considered a replication.

Data from all 12 tests were analyzed for the market-quality ratings. However, since each disorder did not occur in every test, the analyses of the various disorders was based only on those tests in which the disorder occurred. If the analyses had been set up otherwise, the findings might have concealed possible beneficial effects from the modified atmosphere.

USDA personnel checked the modified atmospheres for O_2, CO_2, and CO with an Orsat-type gas analyzer. Gas samples were usually taken both before and after shipment in the MA cars and trailers. The NA vehicles were checked only at destination. In some tests the vehicle doors were opened before USDA personnel arrived, and in these instances, analyses of the atmospheres could not be made.

RESULTS

Transit Temperatures in Cars and Trailers

Transit temperatures should be the same when the effects of normal and modified atmospheres are compared. Average transit temperatures were 37° F. in both the modified atmosphere vehicles and the normal atmosphere vehicles (table 2). Average load temperatures during transit ranged from a low of 33° (trailer number 17) to highs of 39° (cars 2, 4, 7, and 16).

The difference between the warmest and the coolest locations for test cartons in both the MA and the NA vehicles averaged 3° F. and the average transit temperatures of the two vehicles in any given paired shipment did not differ by more than 3°. Further, the warmest load temperatures did not occur consistently in either the MA or the NA vehicles. Therefore, any significant differences in

quality between lettuce shipped in the modified atmosphere and the normal atmosphere vehicles can be attributed to differences in the two atmospheres and not to variances in transit temperatures.

Temperatures of lettuce from all loads averaged 36° F. during loading and 38° during unloading.

TABLE 2.—*Transit temperatures of 12 paired shipments of lettuce sent in rail vehicles with modified and with normal atmospheres from western sources to east coast markets, 1967–68*

Type and No. of vehicle, and vehicle's atmosphere	Average lettuce temperature during loading	Average transit temperature in railcars and trailers						Average lettuce temperature during unloading
		Inside air at ceiling	Load average [1]	Coolest location	Warmest location	Outside air		
						Average low	Average high	
Railcar:	° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
No. 1, modified atmosphere	39	32	36	35	38	----------		35
No. 2, normal atmosphere	39	34	39	37	40	47	80	----------
No. 3, modified atmosphere	35	33	36	35	36	----------		37
No. 4, normal atmosphere	36	33	39	37	40	48	67	40
No. 5, modified atmosphere	37	35	38	36	39	----------		40
No. 6, normal atmosphere	31	31	35	33	37	60	84	35
No. 7, modified atmosphere	34	34	39	36	41	70	96	----------
No. 8, normal atmosphere	37	31	36	35	39	----------		35
No. 9, modified atmosphere	36	33	37	36	39	61	89	38
No. 10, normal atmosphere	34	33	37	36	39	----------		38
No. 11, modified atmosphere	36	31	35	32	38	59	88	35
No. 12, normal atmosphere	35	34	38	36	39	----------		38
No. 13, modified atmosphere	35	35	[2] 38	37	38	35	54	38
No. 14, normal atmosphere	37	----------	[2] 37	37	38	----------		
No. 15, modified atmosphere	34	----------	[2] 37	36	37	----------		
No. 16, normal atmosphere	32	----------	[2] 39	38	40	----------		37
Trailer on flatcar:								
No. 17, modified atmosphere	34	32	33	32	35	55	82	36
No. 18, normal atmosphere	35	33	35	34	36	----------		42
No. 19, modified atmosphere	34	33	36	35	39	57	77	37
No. 20, normal atmosphere	39	31	37	34	39	----------		38
No. 21, modified atmosphere	35	33	38	36	40	65	91	38
No. 22, normal atmosphere	36	33	36	34	38	----------		36
No. 23, modified atmosphere	35	32	36	34	38	65	84	45
No. 24, normal atmosphere	35	36	36	36	37	----------		38
Average:								
Modified atmosphere	35	33	37	35	38	----------		38
Normal atmosphere	36	33	37	36	39	----------		38

[1] Load average based on temperatures of lettuce at 6 locations except as indicated. (See p. 2 for specific locations.)
[2] Average of 3 recording thermometers.

Atmospheric Modifications in Cars and Trailers

After they were loaded and purged at shipping point, the MA vehicles had an O_2 concentration ranging from 0.5 to 4.5 percent (table 3) and averaged 2.3 percent in the cars and 3.1 percent in the trailers. The CO_2 level averaged 0.4 percent in both types of MA vehicles as a result of a slight accumulation of CO_2 from respiration of the lettuce. Carbon monoxide, introduced at shipping point in the MA vehicles, averaged 1.3 percent.

At destination, the O_2 concentration in the MA cars and trailers averaged 6.9 percent and that in the NA vehicles averaged 18.3 percent. The average O_2 level was 5.7 percent in the MA cars and 8.7 percent in the MA trailers. The CO_2 concentration averaged 4 percent in the MA cars and 3.5 percent in the MA trailers, even though bags of lime were present to absorb the CO_2. In the conventional NA vehicles, CO_2 averaged 2.9 in the cars and 1.1 percent in the trailers at destination. The CO concentration in the MA vehicles averaged 0.4 percent at destination.

Market Quality of Lettuce at Destination

At destination, no significant difference was found in the external appearance of lettuce, either with or without wrapper leaves, attributable to the modified atmosphere during transit (table 4). The appearance of untrimmed lettuce from both the MA and NA vehicles averaged fair to good at the arrival examination, and fair after it was held for 4 additional days at 50° F. The appearance of the trimmed lettuce averaged good at arrival, and fair to good after being held for 4 days at 50°.

The appearance of trimmed and untrimmed lettuce from both modified and normal atmosphere vehicles was significantly less attractive at the second examination than at the first examination. Lettuce from both MA and NA vehicles deteriorated at the same rate during the holding period at the laboratory, as indicated by the lack of significant interaction between atmosphere and examination.

In these tests, no significant difference in butt discoloration was found between the lettuce shipped in modified or normal atmospheres. Butt

TABLE 3.—*Oxygen (O_2), Carbon Dioxide (CO_2), and carbon monoxide (CO) concentrations in 12 paired shipments of lettuce sent in rail vehicles with modified and with normal atmospheres from western sources to east coast markets, 1967–68* [1]

Type and No. of vehicle, and vehicle's atmosphere	Atmosphere composition at—					
	Shipping point			Destination		
	O_2	CO_2	CO	O_2	CO_2	CO
Railcar:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
No. 1, modified atmosphere	2.8	0.7	1.1	8.2	2.7	0.6
No. 2, normal atmosphere				14.4	4.2	
No. 3, modified atmosphere	4.0	0		7.8	5.2	.4
No. 4, normal atmosphere				20.3	.3	
No. 5, modified atmosphere	3.3	0	1.0	7.6	3.9	.5
No. 6, normal atmosphere				20.0	.8	
No. 7, modified atmosphere		0	1.5	1.9	5.5	.4
No. 8, normal atmosphere				17.4	3.6	
No. 9, modified atmosphere	.5	.8	1.5	2.0	4.6	.4
No. 10, normal atmosphere				14.0	5.8	
No. 11, modified atmosphere	2.0	0	1.0			
No. 12, normal atmosphere						
No. 13, modified atmosphere				6.6	1.8	
No. 14, normal atmosphere						
No. 15, modified atmosphere	1.0	0	1.8			
No. 16, normal atmosphere						
Trailer on flatcar:						
No. 17, modified atmosphere	3.3	1.2	1.7	10.6	3.8	1.0
No. 18, normal atmosphere				18.3	1.7	
No. 19, modified atmosphere	4.5	1.0	1.0	11.2	4.2	.4
No. 20, normal atmosphere				20.9	.8	
No. 21, modified atmosphere	[2] 2.0			8.8	3.6	0
No. 22, normal atmosphere				19.5	1.0	
No. 23, modified atmosphere	2.5	0	1.0	4.0	2.4	.3
No. 24, normal atmosphere				20.0	.9	

[1] Atmosphere data taken by USDA personnel with Orsat-type gas analyzer.
[2] Data obtained by Transfresh Corp. personnel, who used a Teledyne oxygen analyzer.

discoloration of lettuce from both the MA and NA vehicles increased from a rating of slight at time of arrival to a rating of moderate to severe after 4 days at 50° F. This increase in severity of butt discoloration was statistically significant. There was no interaction between atmosphere and examination; the increase in butt discoloration was the same during 4 days at 50° in lettuce from both atmospheres.

Pink rib occurred in only two paired shipments (table 5), but in these, lettuce from the MA cars had only about half as many heads with objectionable pink rib as lettuce from the companion NA cars (significant at the 5-percent probability level). The incidence of pink rib increased significantly when the lettuce was held for 4 days at 50° F., and more than doubled during this period for lettuce from both MA and NA cars.

TABLE 4.—*Market-quality ratings of lettuce shipments sent in rail vehicles with modified and with normal atmospheres from western sources to east coast markets, 1967–68* [1]

Type of atmosphere and time of examination, and statistical significance	External appearance		Rating for butt discoloration [3]
	Rating with wrapper leaves [2]	Rating without wrapper leaves [2]	
Modified atmosphere:			
On arrival	3. 5	3. 8	3. 2
4 days after arrival [4]	2. 9	3. 7	4. 6
Normal atmosphere:			
On arrival	3. 6	3. 8	3. 3
4 days after arrival [4]	2. 8	3. 3	4. 7
Statistical significance: [5]			
Atmosphere (A)	NS	NS	NS
Examination (E)	**	**	**
A×E	NS	NS	NS

[1] Analyses based on 8 pairs of railcars and 4 pairs of trailers on flatcars. Each paired shipment contained 12 cartons of lettuce from the same field; 6 cartons were shipped in vehicles with modified atmospheres and 6 were shipped in vehicles with normal atmospheres. Each paired shipment was considered a replication.
[2] 1, unsalable; 2, poor; 3, fair; 4, good; 5, excellent.
[3] 1, none; 2, trace; 3, slight; 4 moderate; 5, severe.
[4] Held at 50° F.
[5] NS=not significant; *=significant at 5-percent probability level; **=significant at 1-percent probability level.

TABLE 5.—*Incidence* [1] *of pink rib, decay, brown stain, and tipburn in lettuce shipped in rail vehicles with modified and with normal atmospheres from western sources to east coast markets, 1967–68* [2]

Type of atmosphere and time of examination, and statistical significance	Pink rib	Decay	Brown stain	Tipburn
Modified atmosphere:	*Percent* [3]	*Percent* [3]	*Percent* [3]	*Percent* [3]
On arrival	4. 2	1. 0	16. 3	5. 2
4 days after arrival [4]	9. 8	12. 5	17. 1	7. 6
Normal atmosphere:				
On arrival	8. 3	2. 2	6. 0	4. 2
4 days after arrival [4]	19. 4	14. 3	10. 3	5. 9
Statistical significance [5]				
Atmosphere (A)	*	NS	NS	NS
Examination (E)	**	**	NS	NS
A×E	NS	NS	NS	NS

[1] Condition sufficiently severe to be considered objectionable by the consumer.
[2] A total of 8 pairs of railcars and 4 pairs of flatcars was shipped. Each paired shipment contained 12 cartons of lettuce from the same field; 6 cartons were shipped in vehicles with modified atmospheres and 6 were shipped in vehicles with normal atmospheres. Analyses of disorders were made only for those tests in which the disorder occurred. Analyses were based on: pink rib, 2 paired shipments; decay, 10 paired shipments; brown stain, 7 paired shipments; and tipburn, 4 paired shipments. For pink-rib analysis, each of the 6 test cartons was considered a replication. For analyses of the other disorders, each paired shipment was considered a replication.
[3] Average percentage of heads affected.
[4] Held at 50° F.
[5] NS=not significant; *=significant at 5-percent probability level; **=significant at 1-percent probability level.

Decay occurred in 10 of the 12 paired shipments. About 1 to 2 percent of the lettuce heads had decay at arrival and about 13 to 14 percent had decay after being held for 4 days at 50° F. Findings showed no significant difference in decay attributable to transit atmosphere, and the rate of increase in decay during 4 days at 50° was the same in lettuce from both MA and NA vehicles.

A disorder of lettuce not reported previously in commercial shipments was observed in many of the paired tests (fig. 1). The disorder is characterized by superficial oval to irregular necrotic areas that

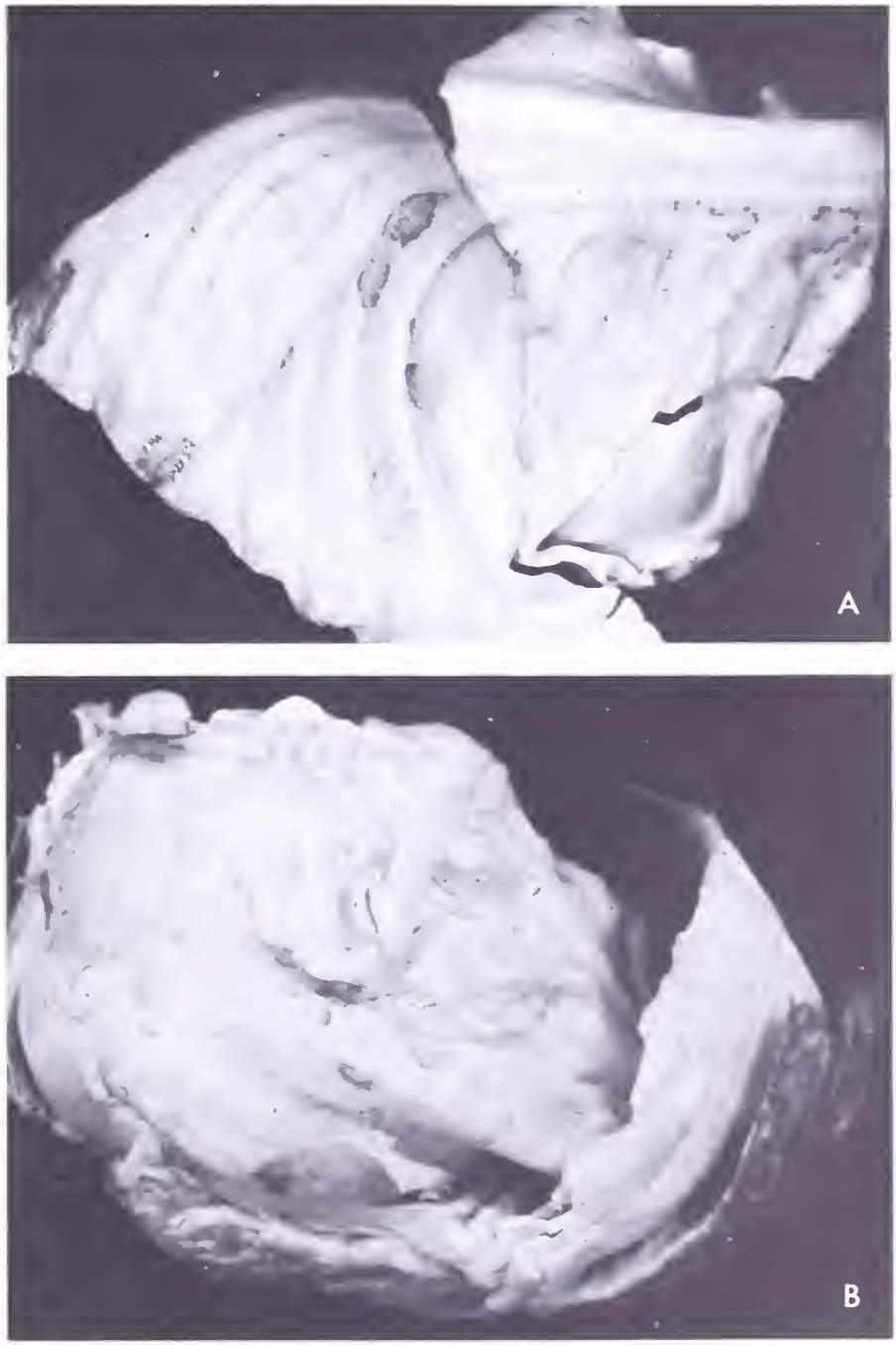

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FIGURE 1.—Brown stain lesions observed in test lots of lettuce at (*A*) Belle Mead, N.J., and (*B*) Chicago, Ill.

are usually ¼ to ½ inch in diameter but sometimes larger, particularly when they coalesce. The affected areas are generally on the outer surface of the head leaves, on or near the midrib, and usually extend toward the basal half of the leaf. When the disorder is severe, the inner leaf surface is often affected, also. The affected areas range from pale straw to brown, and margins are sometimes dark and mottled. We have named the disorder "brown stain."

Although the percentage of heads with brown stain was higher in the 12 MA than in the 12 NA vehicles, the difference was not statistically significant (table 5). The disorder does not appear to be related to low O_2 or high CO levels during transit, but is related to increased CO_2 levels (table 6). The data in table 6 were arranged to readily illustrate this relationship. Lettuce in vehicles that had 1.9 percent or less CO_2 at arrival was free of this disorder, but lettuce in vehicles with 2.4 percent or more CO_2 was not. The CO_2 measured at destination probably does not represent the highest CO_2 concentration that occurred in transit. Barger and others [3] conducted transcontinental shipping tests with asparagus loaded in a 50-foot conventional railcar, mechanically refrigerated, and found that CO_2 levels increased from 2.6 percent in California to a maximum of 5.8 percent in Wyoming, then decreased to 2.9 percent in New Jersey.

Brown stain occurred in lettuce shipped in both the MA and NA vehicles. However, since more MA vehicles than NA vehicles had CO_2 levels above 2 percent at destination, more lettuce shipped in MA vehicles had the disorder than lettuce shipped in NA vehicles. There does not appear to be a correlation between the incidence of the disorder and increasing concentration of CO_2 from 2.4 to 5.8 percent, although detailed laboratory tests will be required to determine whether a correlation exists. Brown stain did not increase significantly during holding for 4 days at 50° F.

Tip burn was not influenced significantly by the transit atmosphere (table 5).

Russet spotting occurred to a very limited extent only in three paired test shipments and only 16 heads out of 864 examined had sufficient russet spotting to be objectionable. Therefore, these data were not analyzed statistically. All of the heads with russet spotting occurred in the three cars with normal atmospheres; 1.4 percent of the heads were affected at arrival and 6.0 percent were affected after 4 days at 50° F.

Rib discoloration was so rare that data for this disorder were not analyzed. There appeared to be no difference in the occurrence of rib discoloration in the MA and NA cars.

Weight loss from lettuce during transit averaged 0.4 percent in both the MA vehicles and the NA vehicles.

DISCUSSION

Modified or controlled atmospheres with low oxygen levels have been shown to reduce the occurrence of russet spotting of lettuce during transcontinental [4] or simulated transcontinental shipments.[5] Not all lettuce is predisposed to this disorder. Reduction of russet spotting was almost the only improvement in lettuce quality attributable to low-oxygen atmospheres in these previous tests. A subsequent series of shipping tests [6] with modified-atmosphere rail equipment indicated that slightly less decay developed in lettuce shipped in low-oxygen vehicles than in normal-atmosphere vehicles. Also, butt discoloration at arrival was slightly less severe in the low-oxygen trailers. However, transit temperatures also averaged about 3° F. lower in the low-oxygen vehicles. Consequently, it is not clear whether the improvement in quality was due to the lower temperatures, the lower oxygen levels, or a combination of these two factors.

Although russet spotting was not prevalent enough in these tests to warrant statistical analyses, all lettuce affected with the disorder occurred in the NA vehicles, a finding which agrees with those of earlier tests. One can assume, therefore, that the modified atmosphere system reported here would be effective in reducing russet spotting of lettuce predisposed to this disorder.

In two of the paired vehicles, pink rib was significantly reduced in the MA vehicles. No statistically significant reduction in pink rib from modified atmospheres has been observed previously. The effects of low-oxygen atmospheres on pink rib is not conclusive, therefore, and should be studied further.

Test findings link CO_2 levels above 2 percent at destination with a lettuce disorder not previously reported in commercial shipments. We call this disorder "brown stain." In an unpublished study conducted by J. K. Stewart and M. Uota at the USDA laboratory in Fresno, Calif., as a result of the discovery of brown stain in the shipping tests conducted for this study, brown-stain lesions were produced by high CO_2 levels similar to those observed in the shipping tests.

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[3] Barger, W. R., Harvey, J. M., Stewart, J. K., Ceponis, M. J., and Lipton, W. J. *California Asparagus: Effect of Transit Environments on Market Quality.* U.S. Dept. Agr. Market. Res. Rpt. 428, 26 pp. 1960.

[4] See footnote 1, p. 1.

[5] Lipton, W. J. *Market Quality and Rate of Respiration of Head Lettuce Held in Low-Oxygen Atmospheres.* U.S. Dept. Agr. Market. Res. Rpt. 777, 9 pp., illus. 1967.

[6] See footnote 2, p. 1.

TABLE 6.—*Relation between incidence of brown stain*[1] *and carbon dioxide (CO_2) levels in paired shipments of lettuce sent in rail vehicles with normal and with modified atmospheres from western sources to east coast markets, 1967–68*

Type and No. of vehicle, and vehicle's atmosphere	CO_2[2]	Heads with brown stain		
		1st exam.[3]	2d exam.[4]	Total
	Percent	*No.*	*No.*	*No.*
Trailer on flatcar:				
No. 25,[5] normal atmosphere	0.4	0	0	0
No. 20, normal atmosphere	.8	0	0	0
No. 24, normal atmosphere	.9	0	0	0
No. 22, normal atmosphere	1.0	0	0	0
Railcar:				
No. 29,[5] modified atmosphere	1.0	0	0	0
No. 27, modified atmosphere	1.2	0	0	0
Trailer on flatcar:				
No. 18, normal atmosphere	1.7	0	0	0
No. 33,[5] normal atmosphere	1.8	0	0	0
Railcar:				
No. 1, modified atmosphere	2.7	24	29	53
No. 8, normal atmosphere	3.6	0	12	12
No. 31,[5] modified atmosphere	3.8	5	18	23
No. 9, modified atmosphere	4.6	0	1	1
Trailer on flatcar:				
No. 26,[5] modified atmosphere	3.3	59	54	113
No. 19, modified atmosphere	4.2	4	7	11
No. 23, modified atmosphere	2.4	3	5	8
No. 21,[5] modified atmosphere	3.6	4	3	7
Railcar:				
No. 30,[5 6]				
No. 28,[5] normal atmosphere	1.9	0	0	0
Trailer on flatcar:				
No. 17, modified atmosphere	3.8	44	31	75
No. 34,[5] modified atmosphere	3.8	21	10	31
Railcar:				
No. 2, normal atmosphere	4.2	23	23	46
No. 7, modified atmosphere	5.5	3	11	14
No. 32,[5 6]				
No. 10, normal atmosphere	5.8	7	17	24

[1] Condition sufficiently severe to be considered objectionable by the consumer.

[2] Measured at destination.

[3] 1st examination made on arrival of lettuce at east coast.

[4] 2d examination made after lettuce had been held for 4 days at 50° F. after arrival.

[5] Data for test vehicles and lettuce quality appear in this table only, for reasons given on p. 2.

[6] No data for atmosphere were obtained at destination.

Watada and others,[7] in their study of the effect of different CO_2 levels on lettuce, found that high CO_2 concentrations (primarily 20, 40, or 60 percent) produced injury. They describe the injury as "variable sized reddish-brown pitted spots along the mid rib; yellow-brown, slimy discoloration of the cut stem with rot in its center; dessicated leaves with yellow oily droplets of exudate; and a general softening of the tissues." This description of CO_2 injury does not agree in general with our description of brown stain (see pp. 7 and 8), but the difference in lesion expression could be due to the differences in CO_2 concentrations.

[7] Watada, A. E., Morris, L. L., and Rappaport, L. *Modified Atmosphere Effects on Lettuce.* Fruit and Veg. Perishables Handling Conf., University, Calif., Davis, Mar. 23–25 Proc., pp. 82–85. 1964.

High CO_2 levels can occur in rail equipment tightly sealed to maintain modified atmospheres, and also in new, tightly constructed rail equipment in which the atmosphere has not been deliberately modified. Railcars appear to be tighter than rail trailers, as evidenced by generally higher CO_2 levels in the cars than in the trailers at destination.

If the incidence of disorders associated with high CO_2 levels become sufficiently objectionable in fresh produce shipped in conventional, tightly constructed cars and trailers, some means of ventilating the vehicles may be desirable.

For modified-atmosphere shipments, either increased amounts of lime or greater exposure of the lime to the load-compartment atmosphere may be desirable.

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